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(54) **Network for minimizing current imbalances in a faradaic battery.**

(57) A circuit for connecting a faradaic battery with circuit means for monitoring the condition of the battery includes a plurality of voltage divider networks VD_1 - VD_n providing battery voltage monitoring node and includes compensating resistors CR_1 - CR_{n-1} connected with the networks to maintain uniform discharge currents through the cells of the battery. The circuit also provides a reduced common mode voltage requirement for the monitoring circuit means by referencing the divider VD_1 - VD_n networks to one-half battery voltage.

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This invention relates generally to electric propulsion vehicles that are powered by faradaic batteries and more particularly to a circuit for interfacing electronic monitoring devices to a faradaic battery to determine the condition or state of health of the battery, the presence of weak or failed cells, while minimizing imbalances in the current drawn from the various cells of the battery.

Electrically propelled vehicles use electric traction motors operated from a battery system mounted in the vehicle. An accurate indication of the condition of the battery is desirable since the available charge is directly related to the range of the vehicle before a recharge of the battery is necessary. Accordingly, electrically propelled vehicles generally include voltage monitoring devices which are electrically connected with the battery system for detecting and indicating the state of health of the battery.

When recharging the battery, it is desirable to equalize the charge in the individual cells of the battery at a set voltage level. Non-faradaic batteries, such as those comprising a plurality of serially connected lead/acid cells, can be brought into balance by application of a low-rate equalization charge. This results in all cells of the battery reaching a full 100% state-of-charge. However, faradaic battery systems, such as those comprising sodium/sulfur cells, cannot be brought into balance by this method, due to the inability of faradaic battery cells to bypass the equalization charge current once the cell reaches full charge. It is therefore important to maintain uniform discharge currents through the cells of a faradaic battery. This need for discharge uniformity also applies to the small currents required by the voltage measuring networks used to monitor battery condition. Even small systematic imbalances in the cell currents will accumulate and result in significant loss of battery capacity over time.

Conventional circuity for interfacing the battery with monitoring equipment is either complex or suffers from severe common mode voltage requirements leading to expensive monitoring equipment.

In accordance with the present invention a plurality of voltage divider networks "n" are connected with a plurality of modules of a faradaic battery. Each module includes a plurality of cells. Each network provides a monitoring point for equipment intended to monitor the condition of the battery. One side of each of the networks is connected to a reference voltage point equal to one-half battery voltage. The monitoring equipment is then referenced to one-half battery voltage to reduce common mode voltage. The other side of each network is connected to respective ones of the modules of the battery and thus provides a means of measuring the voltage at each module to thereby obtain an indication of the condition of the battery cells in any one of the modules. A compensating resistor is associated with "n-1" of the voltage divider networks, and is sized to insure that the current drawn by the networks results in uniform discharge currents through the cells of the battery thus extending battery life.

The invention will now be described further , by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a generalized block diagram showing the invention in the environment of an electric vehicle battery monitoring system.

Figure 2 shows a voltage divider network connected with a battery and providing voltage monitoring signals useful for monitoring the condition of the battery.

Figure 3 shows an embodiment of the circuit of the present invention including eight battery modules.

Figure 4 is a circuit representation of the invention generalized for "n" battery modules.

Referring now to the drawings and initially to Figure 1, a traction battery for an electric vehicle is generally designated 10 and is connected with traction motors generally designated 12 for providing drive current to the motors. The battery 10 is connected via a voltage divider network 14 to monitoring equipment generally designated 16 which monitors the state of health of the battery 10.

Referring to Figure 2 the battery 10 is shown to comprise two banks of battery modules A and B. The bank A includes modules 18-24 and the bank B includes modules 18'-24'. Each of the modules may include 20 cells for a total of 160 cells. The number of modules shown is merely for the purpose of simplifying the description of the invention. A typical battery for use in an electric vehicle may comprise 32 modules of 5 cells each and provide a total voltage of, for example, 320 volts.

The point intermediate the bank A and B is designated REF and provides a reference voltage of 1/2 total battery voltage or 160 volts. This point is used as a reference for the monitoring equipment in order to minimize the common mode voltage requirements of the equipment. In order to monitor the status of the cells in the module A, the monitoring equipment is connected with voltage divider networks 26-32 which provide monitoring nodes V1-V4, between resistors R1, RF1; R2, RF2; R3, RF3; and R4, RF4, respectively. Each of the networks 26-32 has one side connected to REF while the other side is connected with progressively higher voltage nodes in bank A designated 34-40. Bank B is the mirror image of Bank A and the components and connections therein are indicated by prime number.

While the circuit configuration of Figure 2 provides the benefits of reduced common mode voltage for the electronic instrumentation equipment used to monitor battery state of health, unbalanced or unequal discharge currents are created among the battery modules. Note that while the current drawn from

the modules 18 and 18' are equal to the sum of the currents $I + I_2 + I_3 + I_4$, the current through the modules 20 and 20' are reduced by the amount of the current I_2 flowing in the network 28 and 28'. Similarly, the currents in modules 22 and 22', 24 and 24' are reduced by the current I_3 and I_4. While this does not pose a substantial problem with a non-faradaic battery such as lead/acid, these unbalanced discharge currents can, over time, result insignificant loss of battery capacity in a faradaic battery.

Referring now to Figure 3, the circuit of Figure 2 has been modified to solve the problem of discharge current imbalance by the addition of compensating resistors R5,R6 and R7 in bank A and R5', R6' and R7' in Bank B. One side of each of the resistor R5, R6 and R7 is connected with the positive side of module 24 or node 40, while the other side of the resistors R5, R6 and R7 are connected with the positive terminal of the modules 18,20 and 22 i.e. nodes 34,36 and 38 respectively. The resistors R5,R6 and R7 are sized to draw a current substantially equal to that drawn by the networks 26,28 and 30 respectively. Thus, the currents discharged from each of the modules 18, 20,22, and 24 are equal to the sum of the currents I1, I2,I3 and I4 as indicated. Similarly, the currents discharged from each of the modules 18',20' and 24' are equal as a result of the addition of the properly sized compensating resistors R5',R6' and R7'. Figure 4 show a general case for any number of serially connected modules $VS_1...VS_n$ in for example the bank A. The divider networks $VD_1...VD_n$ comprising resistors $R_1...R_n$ and $RF_1...RF_n$, provide monitoring junctions $V_1...V_n$. The networks $VD_1...VD_n$ are connected between the reference node REF and the nodes $H_1...H_n$ and draw currents $I_1...I_n$. The compensating resistors $CR_1...CR_{n-1}$ are connected between the node Hn and the nodes $H_1...H_{n-1}$ and are sized to draw currents equal to those in the respective divider networks $VD_1...VD_{n-1}$. In a preferred embodiment of the invention employing 32 modules of 5 cells each, the resistor $RF_1...RF_n$ are each equal to 10K ohm, while the resistor R1=4K. Where equal currents $I_1...I_n$ are desired and equal voltages exist across the modules $VS_1...VS_n$, the value of the resistors $R_2...R_n$ may be obtained from the equation Ri=iRI+(i-I)RF. For example, R2=2(4)+(2-1)10=18K; R15=15(4)+(15-1)10=200K; and R16=16(4)+(16-1)10=214K. The value of the compensating resistors $CR_1...CR_{n-1}$ may be obtained from the equation $CR_{n-1}=R_n-R_{n-1}$. For example, CR15=214-200=14K; and CR1=214-4=200K.

The monitoring equipment generally designated 16 in Figure 1, is as previously indicated tied to the one-half battery voltage node REF and may take several forms but preferably include a microprocessor which controls a suitable analog multiplexor associated with each of the banks A and B to provide an analog voltage to respective differential amplifiers. After suitable clamping and filtering the outputs of the amplifiers are converted to digital values for processing by the microprocessor in accordance with known algorithms for relating the voltages at the monitoring nodes $V_1...V_n$ to the state of health of the battery.

Claims

1. A circuit for connecting a faradaic battery with means for monitoring the condition of the battery, said battery comprising a plurality of serially connected modules $VS_1..VS_n$, each having positive and negative terminals, said circuit comprising;

   a plurality of voltage divider networks $VD_1...VD_n$ including a monitoring node;

   one side of each of said networks being connected to a reference voltage at one of said terminals of said module VS_1;

   the other side of said networks $VD_1...VD_n$ being connected to the other of said terminals of respective ones of said modules $VS_1...VS_n$ to draw currents $I_1...I_n$ respectively;

   compensating network means including resistors $CR_1...CR_{n-1}$, connecting the other of said terminals of each of said modules $VS_1...VS_{n-1}$ to the other of said terminals of said module VS_n, the resistors $CR_1...CR_{n-1}$ being sized to draw currents substantially equal to the currents $I_1...I_{n-1}$;

   whereby the discharge current from the modules of the battery is substantially uniform and equal to the sum of the currents flowing in the divider networks $VD_1...VD_n$.

2. A circuit as claimed in Claim 1, wherein the divider networks $VD_1...VD_n$ include a first resistor $R_1...R_n$ and a sound resistor $RF_1...RF_n$.

3. A circuit as claimed in Claim 2, wherein the voltages across each module is substantially equal.

4. A circuit as claimed in Claim 3, wherein the currents drawn by each divider network are substantially equal.

5. A circuit as claimed in Claim 4, wherein the resistors connected between said monitoring node and said reference node are of substantially equal resistance value.

6. A circuit as claimed in Claim 5, wherein the sum of the resistors in the voltage divider network VD_n is substantially equal to the sum of the resistors in the respective voltage divider networks $VD_1..VD_{n-1}$ added to the compensating resistors $CR_1...CR_{n-1}$ respectively.

7. A circuit for connecting a faradaic battery with means for monitoring the condition of the battery,

said battery including first and second banks of serially connected cells forming a plurality of serially connected modules $VS_1..VS_n$ having terminal nodes $H_1...H_n$ and having a reference node between said first and second banks at substantially one-half of the total voltage of said battery, each bank of said circuit comprising;

a plurality of voltage divider networks $VD_1...VD_n$ each including first and second serially connected resistors providing a monitoring node therebetween;

said networks $VD_1...VD_n$ being connected between said reference node REF and nodes $H_1...H_n$ respectively to draw currents $I_1...I_n$ respectively;

compensating resistors $CR_1...CR_{n-1}$ respectively connecting nodes $H_1...H_{n-1}$ with node H_n, the resistors $CR_1...CR_{n-1}$ being sized to draw currents substantially equal to the currents $I_1...I_{n-1}$,

whereby the discharge current through each modules of the battery is substantially uniform and equal to the sum of the currents flowing in the divider networks $VD_1...VD_n$.

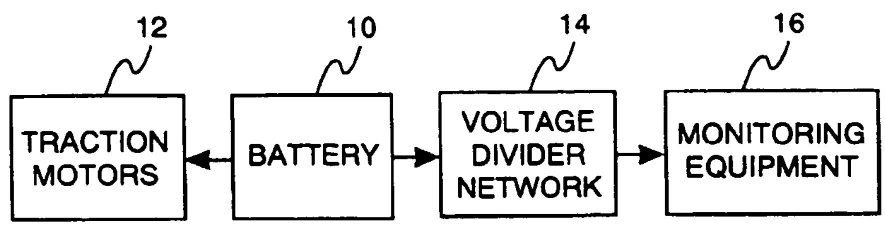

12
10
14
16
TRACTION MOTORS
BATTERY
VOLTAGE DIVIDER NETWORK
MONITORING EQUIPMENT

FIG. 1

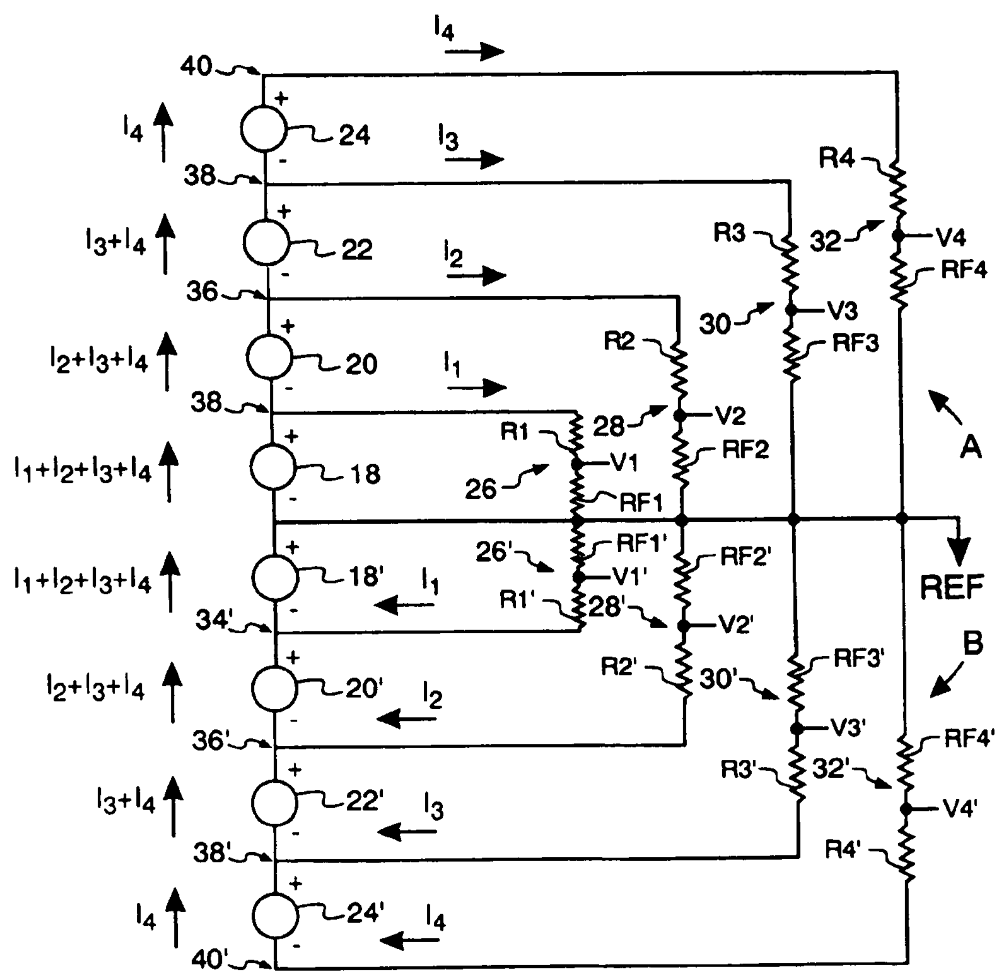

I4
40
24
I3
38
22
I2
36
20
I1
18
R4
32
V4
RF4
R3
30
V3
RF3
R2
28
V2
RF2
R1
26
V1
RF1
A
REF
B
RF1'
26'
V1'
18'
R1'
28'
34'
V2'
RF2'
R2'
30'
20'
36'
RF3'
V3'
R3'
32'
22'
38'
RF4'
V4'
R4'
24'
40'
I3+I4
I2+I3+I4
I1+I2+I3+I4

FIG. 2

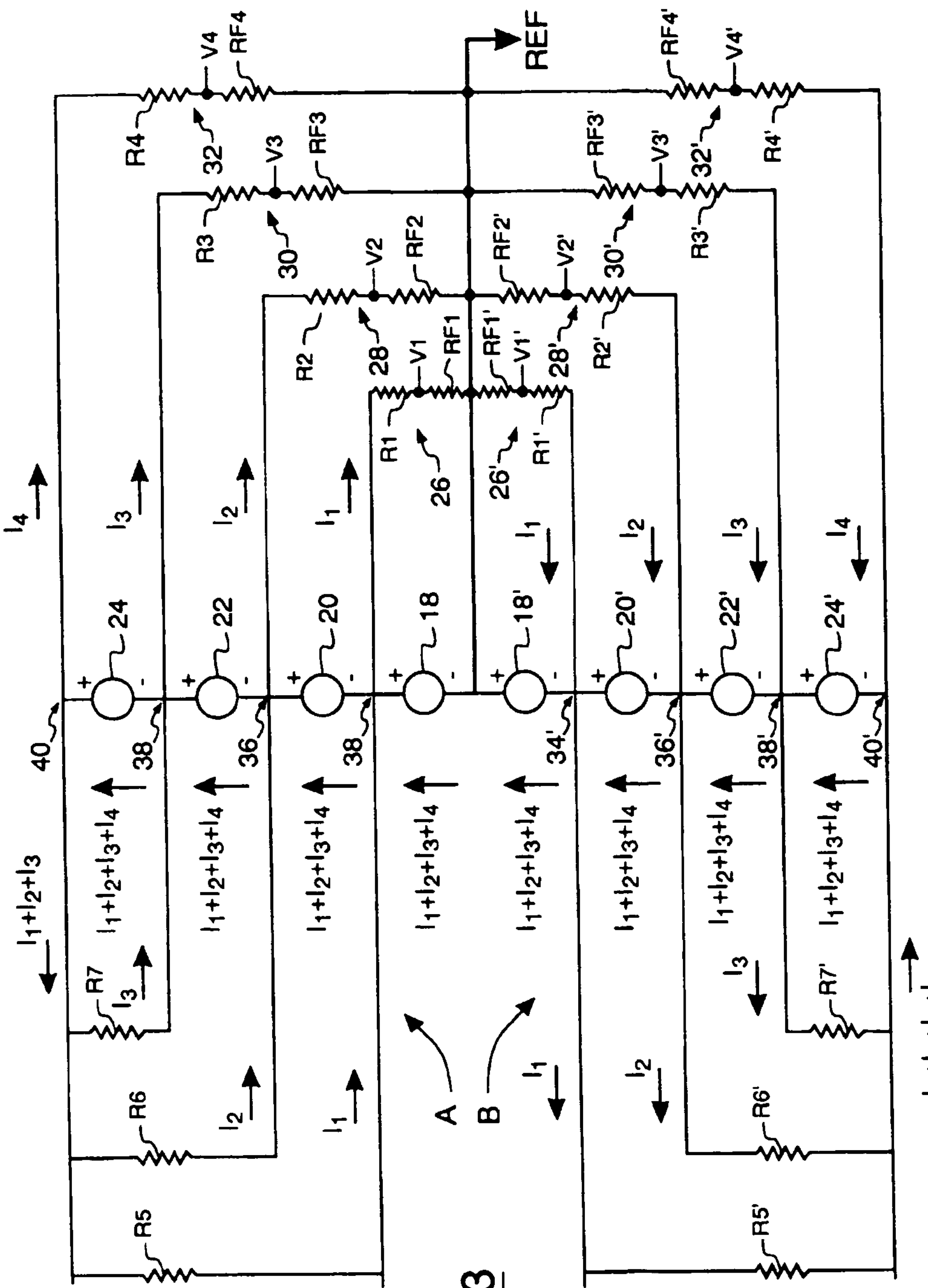
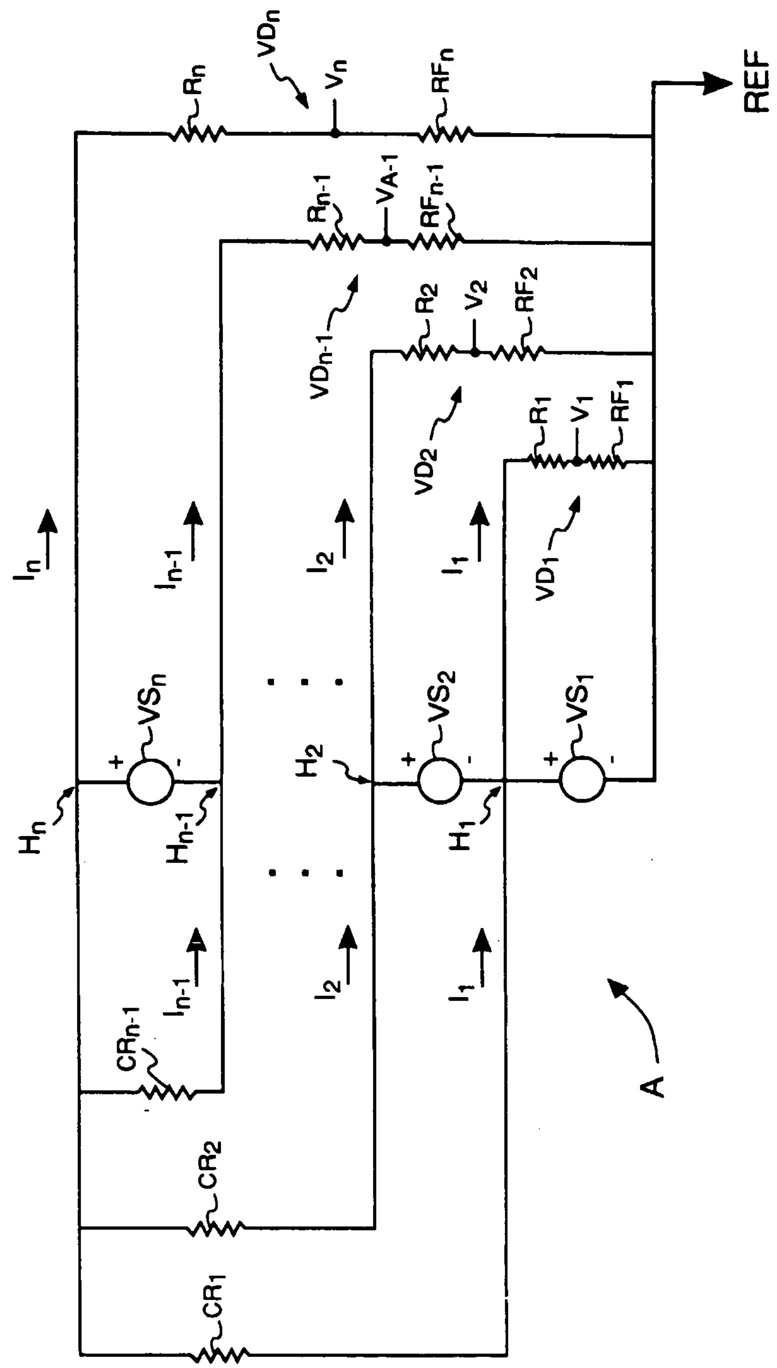

REF
V4
RF4
R4
32
V3
RF3
R3
30
V2
RF2
R2
28
V1
RF1
R1
26
RF1'
V1'
28'
R1'
26'
RF2'
V2'
30'
R2'
28'
RF3'
V3'
32'
R3'
RF4'
V4'
R4'
I_4
I_3
I_2
I_1
24
22
20
18
18'
20'
22'
24'
40
38
36
38
34'
36'
38'
40'
$I_1+I_2+I_3+I_4$
$I_1+I_2+I_3$
R7
R6
R5
R7'
R6'
R5'
A
B

FIG. 3


R_n
VD_n
V_n
RF_n
REF
R_{n-1}
V_{A-1}
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R_2
V_2
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R_1
V_1
RF_1
VD_2
VD_1
I_n
I_{n-1}
I_2
I_1
VS_n
VS_2
VS_1
H_n
H_{n-1}
H_2
H_1
CR_{n-1}
CR_2
CR_1
A

FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 4844

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	EP-A-0 080 164 (B.B.C.) * figure 2 * ---		G01R31/ 36 G01R31/36
A	DE-A-3 940 929 (FRAUNHOFER) -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			G01R

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	21 SEPTEMBER 1993	HOORNAERT W.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P0401)

From: Kendrick Lo <klo@bereskinparr.com>
To: John FitzGerald <John.FitzGerald@cryptologic.com>
Cc: Vlad Dunaevsky <Vlad.Dunaevsky@cryptologic.com>
Date: Monday, June 28, 2004 2:59 PM
Subject: Re: Side wagering B&P 13964-8

Hi John:

Just a reminder that we are still awaiting your review of this application before we proceed further with the filing procedures. For your convenience, please find attached the most recently updated version of the draft patent application, which incorporates the other inventors' suggestions.

If you have any questions or concerns, please let me know.

Regards,
Kendrick

--

From: "John FitzGerald" <John.FitzGerald@cryptologic.com>
Date: Thu, 17 Jun 2004 17:29:47 -0400
To: "Vlad Dunaevsky" <Vlad.Dunaevsky@cryptologic.com>, "Kendrick Lo (E-mail)" <klo@bereskinparr.com>
Subject: RE: Side wagering B&P 13964-8

I will let you know once I have finished my review.

John Kennedy FitzGerald (john.fitzgerald@cryptologic.com)

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-----Original Message-----
From: Vlad Dunaevsky
Sent: Thursday, June 17, 2004 5:26 PM
To: Kendrick Lo (E-mail); John FitzGerald
Subject: Side wagering B&P 13964-8

Hi Kendrick,
We Sergiy Rozkin, Serge Bourenkov and I have looked a Side

wagering system application form proposal, except John Fitzgerald. From technical, logical and graphical points of view everything looks **"Okay"**

We think that we can proceed with this application, but please contact with John Fitzgerald for final approval.

Thanks

VLAD DUNAEVSKY RESEARCH & DEVELOPMENT MANAGER
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